EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/73-13
14 May 1973

INTERSECTING STORAGE RINGS COMMITTEE

PROPOSAL FOR A CONTINUATION WITH INCREASED SENSITIVITY OF THE SEARCH FOR $e^{\pm}$, $e^{+}e^{-}$ PAIRS, HIGH TRANSVERSE MOMENTUM $\pi^{\pm 0}$, AND MULTIPLE PION CORRELATIONS IN COLLISIONS WITH HIGH TRANSVERSE MOMENTUM

CERN - COLUMBIA - ROCKEFELLER COLLABORATION

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1. HISTORY

In 1969, a CERN-Columbia-Rockefeller Collaboration proposed a program of research at the ISR based on the expectation that pp collisions at high energy could be used as a tool for studying weak and electromagnetic interactions. In particular, we proposed to look for the reactions:

$$p + p \rightarrow W^{\pm} + \text{anything} \quad \lfloor\!\rightarrow e^{\pm} + \nu_e\ (\bar{\nu}_e) \tag{1}$$

and

$$p + p \rightarrow \text{"}\gamma\text{"} + \text{anything} \quad \lfloor\!\rightarrow e^{+} + e^{-} \tag{2}$$

These reactions are closely related by CVC such that from the yield of virtual photons of mass M the production cross-section of a weak vector boson of the same mass can be estimated, should such an object exist. In addition, as a by-product, we would obtain the π^0 spectrum from strong interactions.

The experimental arrangement consisted of a large aperture array of lead-glass blocks designed to measure the energy of photons and electrons emitted near 90° relative to the pp collisions - the kinematical region where the competing strong production of hadrons is least and where the far weaker production of leptons via semi-weak and electromagnetic reactions may be more easily identified.

The analysis of about 4×10^{10} pp collisions observed from May to December 1972 is now nearing completion and the following relevant conclusions may be stated$^{1)}$:

i) The detection aperture, combined with the mean luminosity achieved in the above period, has resulted in a sensitivity such that one observed event corresponds to a cross-section of $\sim 3 \times 10^{-36}$ cm^2.

ii) An unexpectedly large yield of photons, largely derived from π^0's emitted inclusively near 90°, has been observed. This large yield was not foreseen by most of strong interaction theory; theory which had installed in it, the "empirical" notion of limited transverse momentum, in turn derived from cosmic rays and data at lower energy accelerators. Moreover, the data at different s values show that simple Feynman scaling is broken at large transverse momenta.

iii) The search for single electrons from reaction (1) has yielded no events above 7.5 GeV/c and no "peak" (defined by a grouping of $\gtrsim 4$ events within a resolution bin of 10%) above 5.5 GeV/c. (Although these numbers are provisional at the time of writing, they are adequate for the purposes of this proposal.) This result is relevant to the existence of $W^{\pm}$'s with mass between ~ 11 GeV and 50 GeV.

iv) The yield of e^+e^- pairs from reaction (2) above a pair mass of ~ 5 GeV corresponds to $\sigma \lesssim 4 \times 10^{-34}$ cm^2. This number is relevant to any predictions for time-like virtual photons emitted in hadronic collisions. Such predictions are contained in a very large body of literature that attempts to generalize the physics of deeply inelastic lepton-hadron processes.

v) The spatial and time resolution of the glass array and the physics of happenings at 90° in the ISR are such that various backgrounds have appeared which limit the sensitivity of the present arrangement. It has turned out that these backgrounds appear at just about the level of the statistical limitations which are contained in the data we have on hand. Thus it was correct to terminate the present stage of the research in December 1972.

2. SACLAY COLLABORATION

Since a part of the Saclay program overlaps the physics interests of CCR, a collaboration was proposed in which the double-arm glass array of CCR would be combined into a single detector following one of the two 90° magnets which form part of the Saclay detector. The resulting combination of magnetic analysis and total energy measurement decreases the sensitivity of this arrangement to backgrounds, but at the cost of a loss of solid angle. This loss of intensity will in part be compensated by improved average luminosity during the exposure of this combined arrangement which is expected to begin in June 1973 and to last for essentially the remainder of 1973. We consider that this experiment will provide a very important bridge to the next phase of our research which is the basis of this proposal.

3. SEARCH FOR DILEPTONS - PHASE II

We base this proposal on the expectation that ISR luminosity will increase to ∿ 2×10^{31} for the initial period of the running of Phase II in 1975. We understand that several possibilities exist which could reasonably be expected to provide such an increase. Among them are normal machine improvements including better vacuum conditions, and use of the new PS booster ring injector. In addition, the apparatus which we propose to construct would be compatible with one or more of the proposals now under consideration for the installation of a low-β section at the ISR. Such a project could be expected to provide an additional factor of 4 or more in the luminosity, and might be made available in the 1975-1976 period.

The CCR group, possibly joined by additional collaborators, would then undertake to build a new detector, designed to operate in this new environment. The acceptance of the new detector would be 2-4 times larger than that of Phase I. The apparatus would be designed to cope with the backgrounds in so far as we can anticipate them and to achieve a level of sensitivity such that one detected event would be equivalent to a cross-section of ∿ 6×10^{-38} cm^2. The remainder of this proposal sketches the proposed arrangement and discusses the reasons for this new probe into core pp collisions.

4. THE ARRANGEMENT

Figures 1a and 1b are schematic representations of the proposed new arrangement. It will consist of

a) A cylindrical MWPC array around the interaction region, subtending a 2π azimuth and a ±40° polar aperture around 90° relative to the ISR beam direction.

b) A solenoidal magnetic field[2)] of 15 kG with a useful radius of ∿ 75 cm, providing a practical $\int B\,dl$ of ∿ 10 kG · m (see Figs. 2a and 2b).

c) A lead-glass array covering a part of the 2π azimuthal angle and about one-half of the polar angle. Our sketch indicates an array roughly twice as large as our present array but occupying three times the solid angle because of the improved geometry and the deletion of subsidiary small blocks (old "hadron-veto" blocks) which are no longer required.

Comments:

i) The solenoidal field has large elements of simplicity and will be constructed from aluminium-stabilized superconductor in order to keep the winding thickness to less than one radiation length. M. Morpurgo has made a preliminary design of such a solenoid; the order of magnitude of the effort is illustrated by his rough cost estimate of 1 MSF. Studies by the ISR Division of the magnetic configuration shown in Fig. 2 have shown no incompatibility with ISR operation. Moreover, the structure is physically compatible with at least one of the low-β section geometries now under consideration.

A second design which utilizes a solenoid at 90° to the beam direction has also received some consideration. It appears feasible and is probably compatible with ISR operation. For the purpose of this proposal, we confine our discussion to the longitudinal solenoid which, at present, appears to be the favoured alternative.

ii) Track fitting for high multiplicity events is a formidable problem. We have decided that some developmental work is essential both to improve the standard space resolution of MWPC and to have a coupled X-Y read-out. We have been encouraged by recent results of Charpak et al.$^{3)}$ (for which we have provided collaborative assistance). We will also collaborate in the design and construction of a prototype MWPC operating in the drift mode. We expect to attain space resolution $\lesssim$ 0.5 mm. The coupled X-Y read-out should appreciably reduce computer track-fitting times by comparison with the use of chambers with separate X and Y modules. Fast time resolution of $\lesssim$ 10 nsec and time gates of ∿ 40 nsec are also requirements.

iii) Radiation damage to the Pb-glass has been found to be larger than had been anticipated. This effect results in a decrease in the optical transmission which introduces a slow time shift in the energy calibration of the counters and a gradual decrease in resolution. We now know that most of the damage to our original array occurred when the array was initially unshielded and from radiation during ISR beam testing and filling, rather than during data taking operation. We have also found, after extensive testing, that the Pb-glass blocks can be restored to their original transmission (or very nearly so) by exposing them for a few days to an ultra-violet source. Adequate radiation shielding, together with periodic calibration and ultra-violet treatment, will allow us to keep this problem well under control. Moreover, the new arrangement provides the possibility to continuously calibrate the glass detector in place, thus avoiding one of the major problems of Phase I. This will be done by intentionally converting some γ-rays from π^0's and triggering on the resulting electrons whose momenta are determined by the magnetic spectrometer to better than 5% at 3 GeV/c. "Straight through" pions and muons also provide a monitoring point at 0.5 GeV/c if suitable triggering is provided.

iv) The major background to the search for single electrons observed in Phase I is an overlap (random or otherwise) of a π^0 and a charged track ($\pi^\pm$). The determination of the charged particle momentum by magnetic deflection and the requirement that it agree with the energy measured in the Pb-glass array will reduce this background to a negligible level.

v) A similar comment applies to Dalitz conversion or vacuum wall conversion of one of the π^0 γ-rays. For the energy range in which we are interested, the e^- (or e^+) track will overlap in the Pb-glass with the unconverted π^0 γ-ray. As a result the magnetic momentum will fail to agree with the energy measured in the Pb-glass array.

vi) The "leakage" of high P_T charged pions, via nuclear interaction in the glass is well studied in this kind of detector. We have also studied $\bar{p}$ and find very similar results. We assume that kaons, protons and neutrons are also similar. Roughly 3×10^{-3} of these hadrons of energy E give a pulse height of $E \pm \Delta E$ in lead-glass, where ΔE is the over-all resolution. We obtain an additional factor ~ 10 by demanding a shower in 1 radiation length before the glass. A further factor of 2-4 may, if needed, be obtained from the fact that hadronic cascades inevitably produce some < 1 GeV pions which leak out of the glass and may be caught in a "rear hadron rejector". It then appears safe to assume a suppression of $\sim 3 \times 10^{-4}$ on hadrons.

vii) It is in any case clear that e^+e^- pair signals should be background-free out to the limit of the statistics envisioned in this proposal.

viii) We note that the arrangement also provides a charged particle momentum analysis in coincidence with large P_T π^0 events. So-called "long range correlations" will be open to detailed study. We can address the problem of what it is that recoils: single particles? jets? The aperture is such that good statistical data can be provided even at $P_T \gtrsim 10$ GeV/c; as such, this is an extremely powerful probe of small distance hadrodynamics.

ix) As a rough measure of the effort, the cost of the detectors, including MWPC's and read-out, is estimated at 0.8 MSF, to be shared among the collaborating institutions.

5. PHYSICS RATIONALE

5.1 $p + p \to e^+e^- +$ anything

In our Phase I experiment, we have observed a total of 7 events which are candidates for this reaction from a total of 1.5×10^{10} interactions at $\sqrt{s} = 52.7$ GeV. All of these candidate events have effective masses between 3 GeV, our threshold, and 6 GeV. From the same data set, we can demonstrate that we expect 7.8 ± 4 events from background sources. Thus our signal (-0.8 ± 4) is consistent with zero for all e^+e^- pair masses above 3 GeV.

Drell and Yan[4)], Bjorken, Berman and Kogut[5)], Brandt and Preparata[6)], and many others have suggested models which permit the scaling of the cross-section for the production of lepton pairs of mass M from lower energy data to the ISR domain. Curve (1) of Fig. 3 illustrates the expected yield from the Drell-Yan model scaled from the BNL dimuon data[7)]; curve (2) is the cross-section expected from the two-photon exchange process[8)]. Curve (3) is the 90% confidence level upper limit for $d\sigma/dm$ from our Phase I data using the Drell-Yan production model to estimate our detection efficiency. Curve (4) is our estimate of the cross-section upper limit we would reach with the proposed Phase II if no events above background were to be observed.

Unfortunately, the Drell-Yan model is expected to scale as m^2/s and there is no range in this variable as measured at BNL which overlaps with our Phase I ISR range in m^2/s in which we are sufficiently sensitive to confirm or deny convincingly this important concept. Clearly Phase II will provide a wide mass range over which the parton-parton annihilation

(Drell-Yan) model, the light cone scaling, and others can be tested sensitively. Moreover, the production of pairs via QED processes (curve 2), which must almost certainly be present, is well within our range of observation.

In addition, we can continue the search for neutral objects, e.g. the neutral intermediate boson $W^0 \rightarrow e^+e^-$, with nearly two orders of magnitude greater sensitivity.

5.2 $W^\pm \rightarrow e^\pm + \nu\ (\bar{\nu})$ sensitivity

Phase I has placed upper limits on the production of charged intermediate bosons, or for that matter, on any charged meson of mass M decaying via a two-body decay mode into an electron and another light particle (ν, γ, π, etc.). The upper limit from Phase I on $\sigma_{e\nu}(m)$ as a function of m is shown as curve (1) of Fig. 4.

To indicate the present sensitivity, curve (2) shows B $\sigma_W(m)$ versus m as predicted by Drell-Yan scaling combined with CVC. B is taken to be the reasonable, but somewhat arbitrary, value of 1/4. Thus if Drell-Yan scaling were correct, our data would rule out the existence of $W^\pm$ with the assumed value B = 1/4 from about 12 to 21 GeV.

Obviously it would be desirable to establish clearly the e^+e^- pair cross-section $d\sigma/dm$, as remarked in Section 5.1 above. Then the sensitivity, assuming only CVC, for the $W^\pm$ search would be firmly established. For the single electron (positron) search proposed in Phase II, curve (3) of Fig. 4 gives the estimated upper limit sensitivity level. In this case, even if the pair cross-section were 1/10 of the Drell-Yan prediction, we would be sensitive for W masses out to about 40 GeV. The expected improvement in our background at low masses should also allow much greater sensitivity at low masses.

5.3 Neutral currents

We remark here that if neutral currents (virtual W^0 or Z^0) exist, they will decay into e^+e^- pairs and interfere with virtual γ production. If the interference violates parity and/or charge conjugation, the effect may possibly be observable. The magnitude of the interference becomes ∿ 10% at $M_{ee} \sim 20$ GeV. The number of pairs above this mass, expected on the basis of the Drell-Yan model, is only ∿ 50. However, an added improvement in luminosity now <u>of a factor of 5-10</u> will bring this new piece of physics into possible observation.

5.4 Strong interactions at large P_T

Three qualitative features are already clear from our present data:

i) The production of π^0 falls much more slowly with increasing P_T than the exponential behaviour observed for $\pi^\pm$ below $P_T = 1.2$ GeV/c.

ii) With the present apparatus and luminosity, events are observed out to P_T in the range 7 to 9 GeV/c.

iii) The cross-sections at large values of P_T are smaller for smaller values of s.

Analysis of these data remains to be completed and comparison made to a number of new theoretical ideas generated by our preliminary data. But, in any case, it appears that our observations provide a method to make detailed studies of strong interactions at extremely small distance.

Clearly, in addition to pressing to still higher values of P_T, the next logical step is to study the correlations of the pions produced in events with large P_T. Our present apparatus limits us to the study of energy correlations π^0-π^0 and angular correlations only for charged pions since we cannot measure energy for $\pi^\pm$. Moreover, the number of events above 6 GeV is too small to give statistically meaningful results.

Since our apparatus provides an energy sensitive trigger, we can make full use of the 10-50 times higher rate to accumulate events selectively at very high values of P_T. With the magnetic field-lead-glass-combination, correlations for all combinations of charged and neutral pions are measurable. Our excellent angular and space resolution will allow us to analyse events in which two or more particles are produced within a small cone (which we observe in our present data as a frequent phenomenon). At the same time, the solid angle acceptance is large enough to search for jet-like phenomena in the region where momentum conservation should tend to concentrate such events.

REFERENCES AND FOOTNOTES

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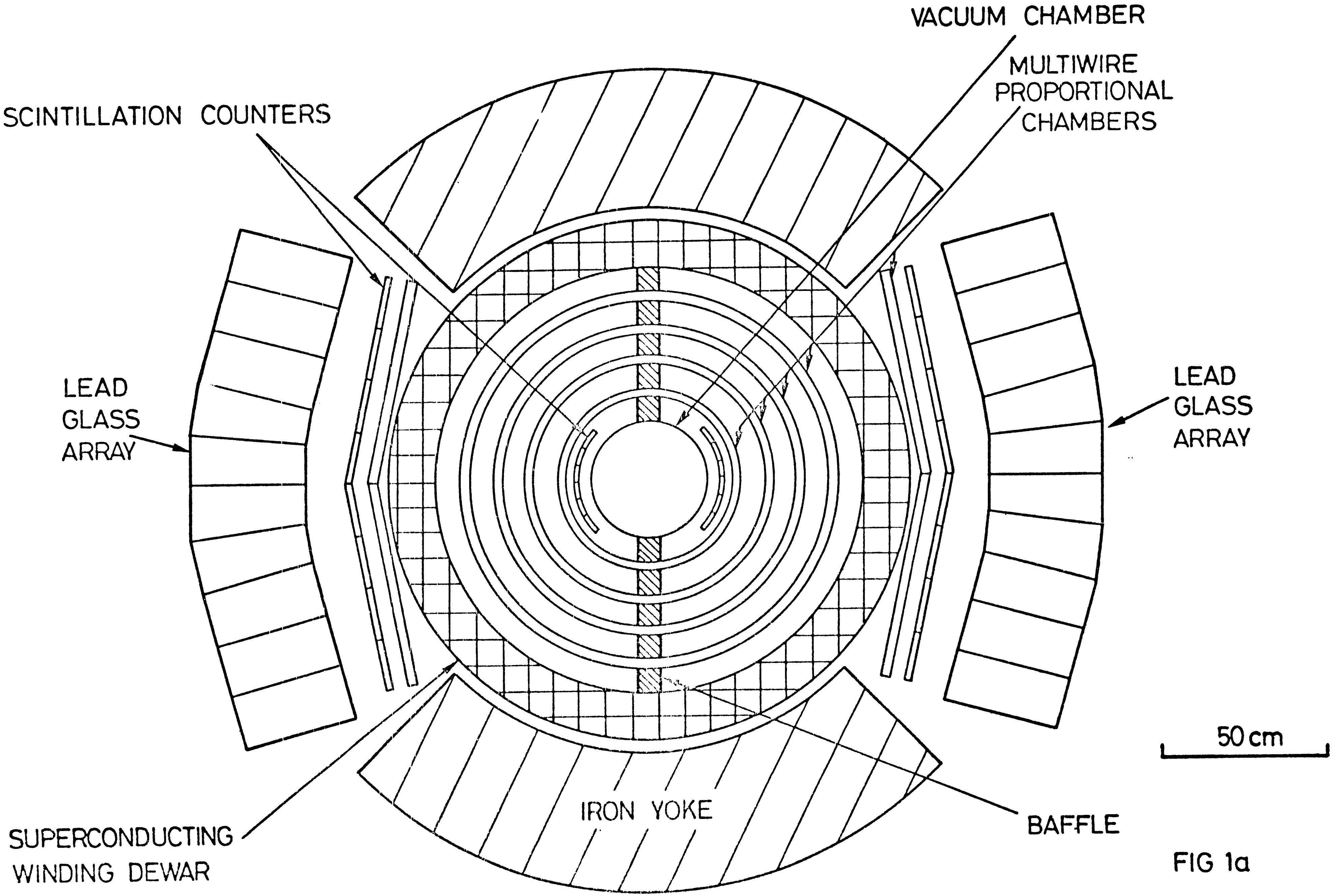
VACUUM CHAMBER
MULTIWIRE PROPORTIONAL CHAMBERS
SCINTILLATION COUNTERS
LEAD GLASS ARRAY
LEAD GLASS ARRAY
50 cm
IRON YOKE
BAFFLE
SUPERCONDUCTING WINDING DEWAR

FIG 1a

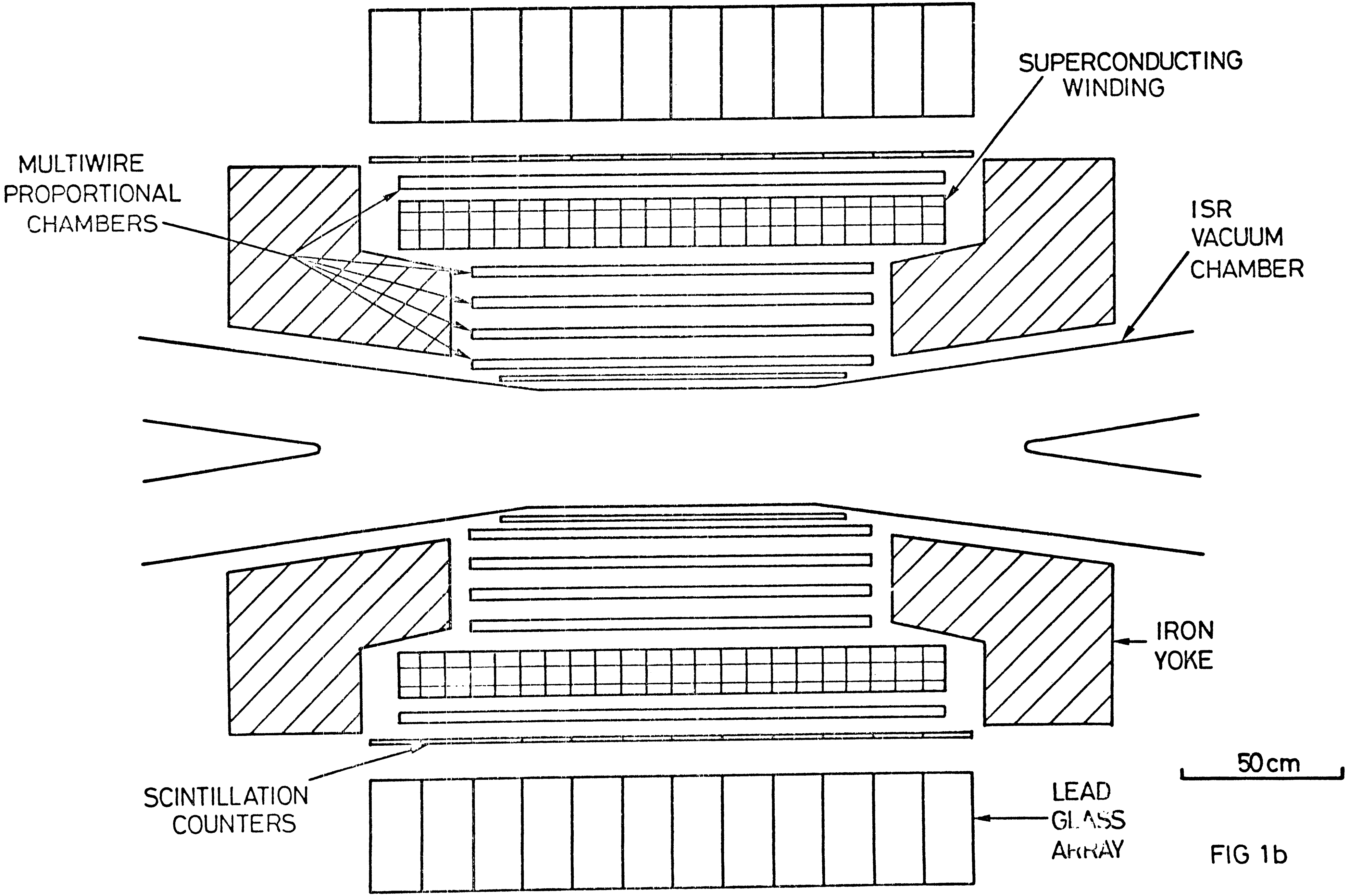
SUPERCONDUCTING WINDING
MULTIWIRE PROPORTIONAL CHAMBERS
ISR VACUUM CHAMBER
IRON YOKE
50cm
SCINTILLATION COUNTERS
LEAD GLASS ARRAY

FIG 1b

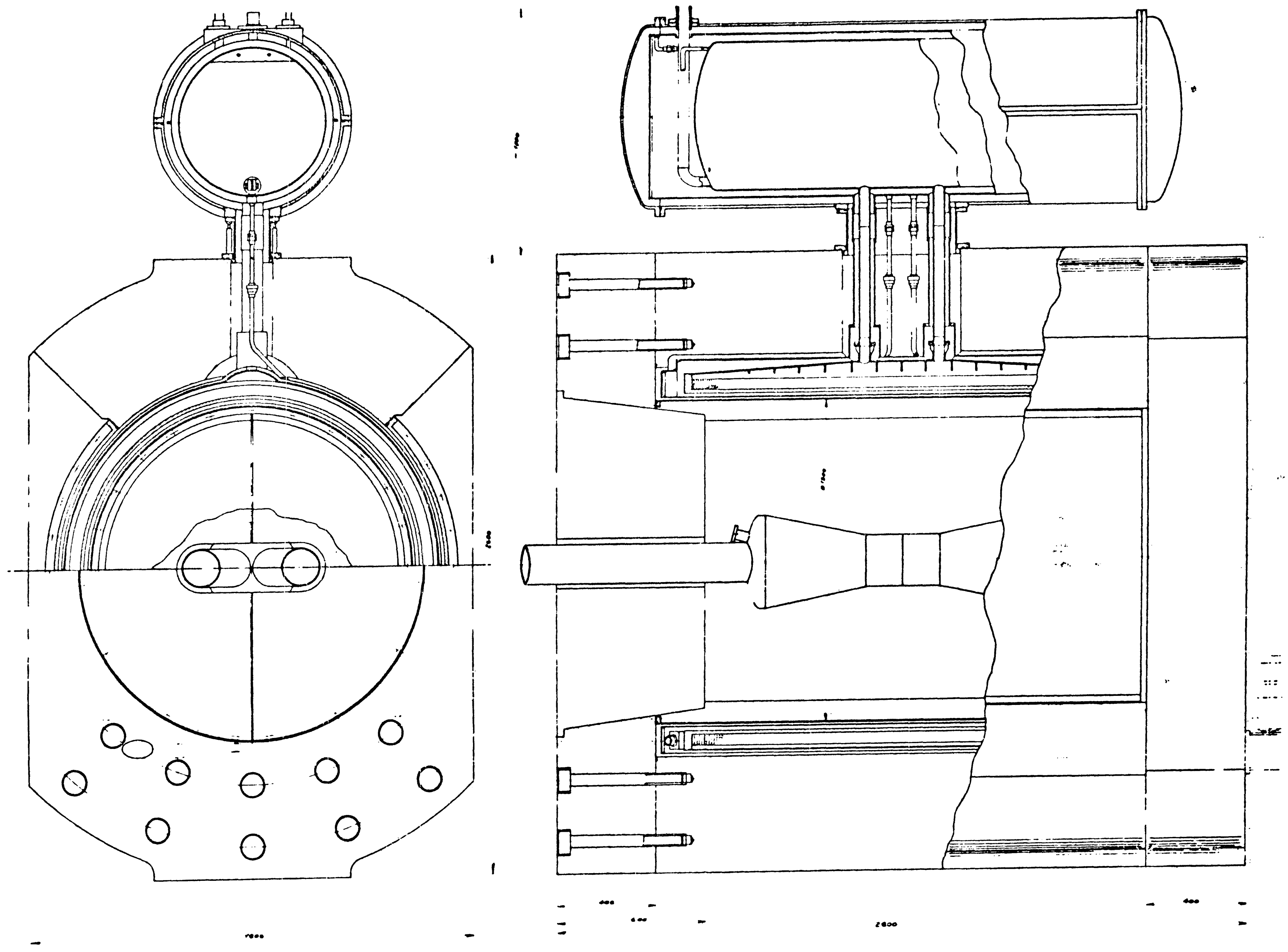

FIG 2b

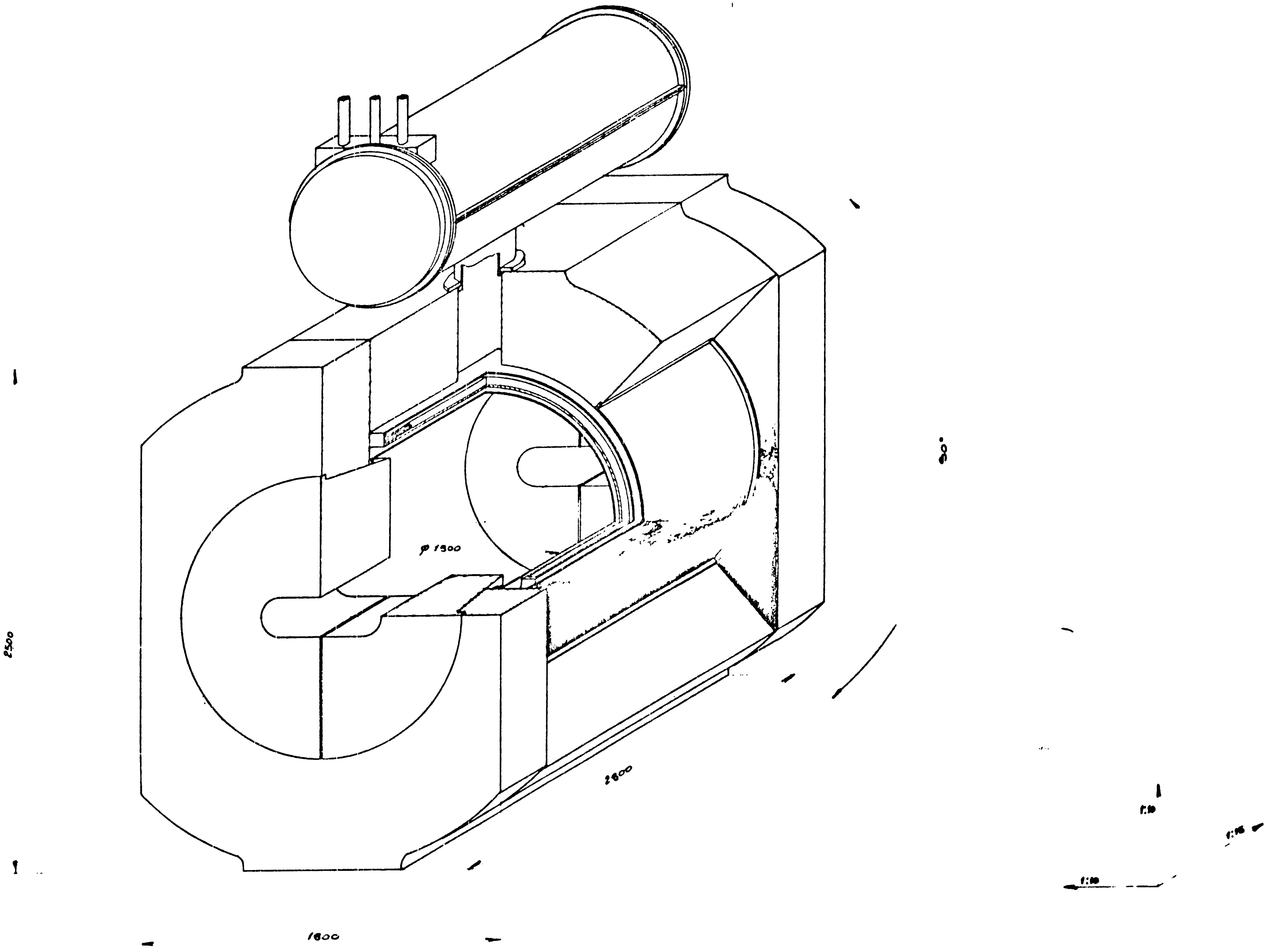

FIG 2a

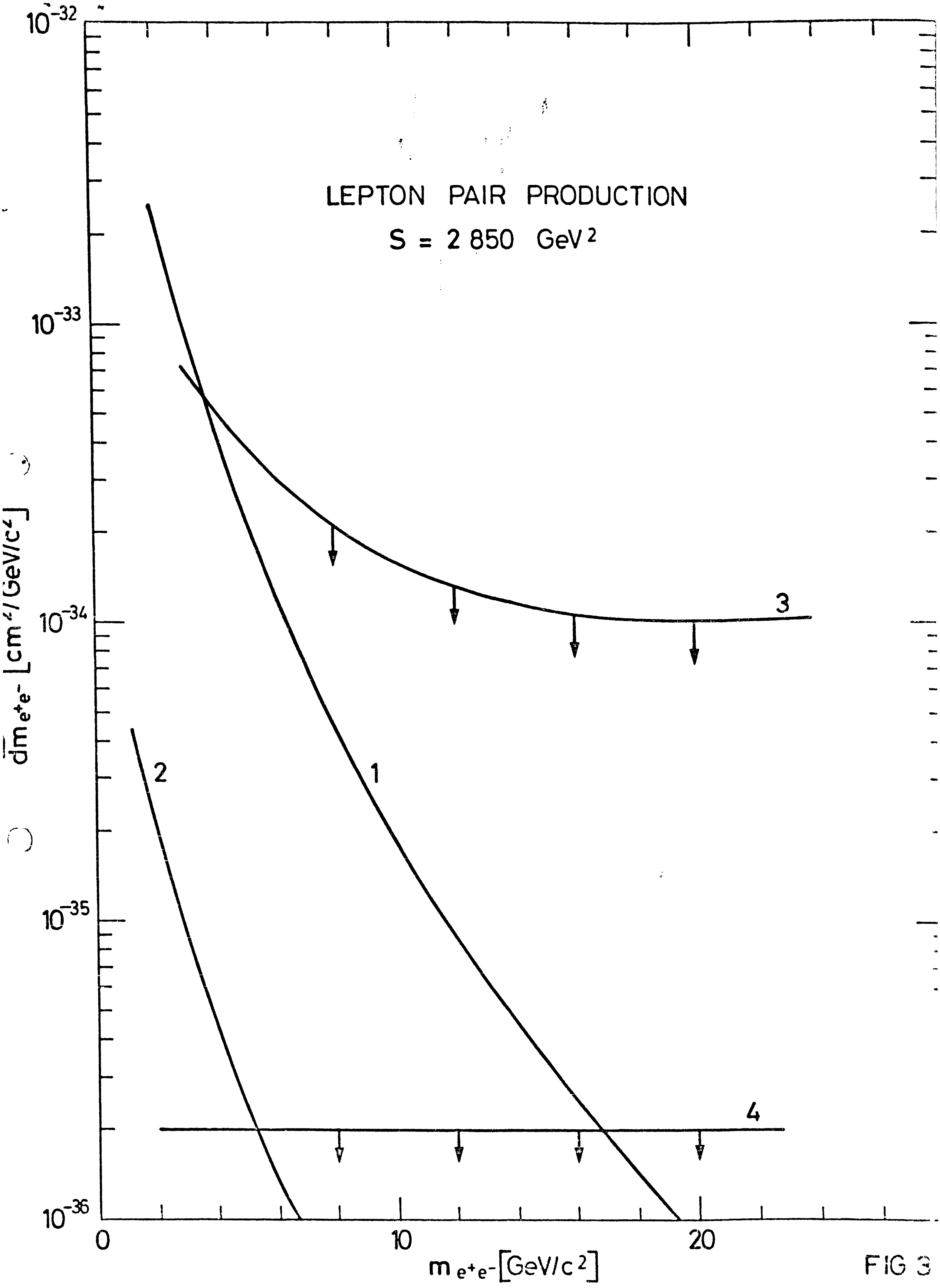
LEPTON PAIR PRODUCTION
S = 2 850 GeV²
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
dm e+e- [cm²/GeV/c²]
1
2
3
4
0
10
20
m e+e- [GeV/c²]

FIG 3

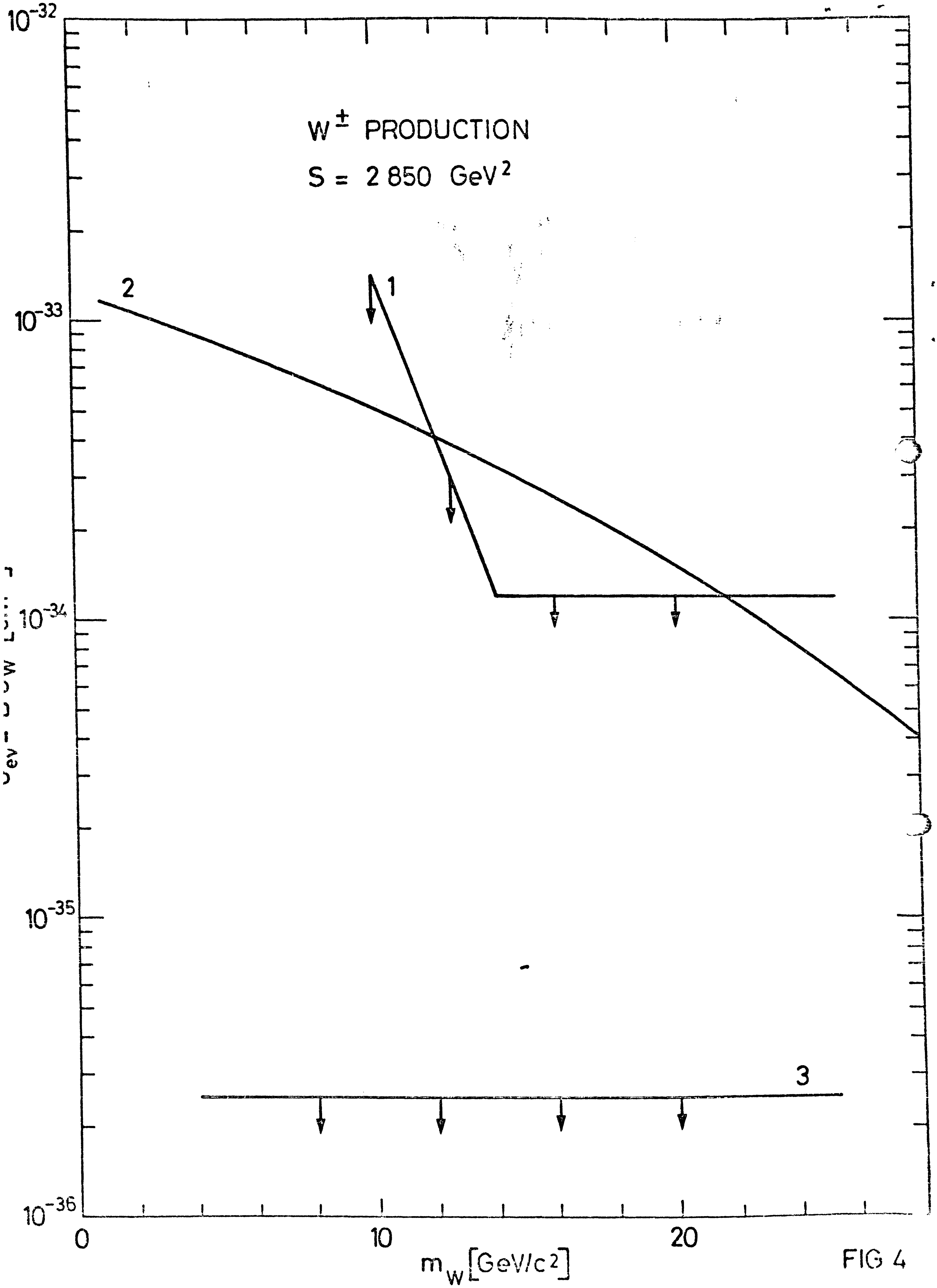
W± PRODUCTION
S = 2 850 GeV²
1
2
3
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
0
10
20
m_W [GeV/c²]

FIG 4